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Cost effective future derailment mitigation techniques for rail freight traffic management in Europe

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Abstract

Safe and reliable traffic management is vital for uninterrupted and successful operation of the European rail network, where mixed traffic (i.e. freight and passenger) services are run. Although rail freight derailment is infrequent, its consequences can be severe and may result in different forms of costs, including infrastructure; rolling stock; traffic disruptions; injuries and fatalities. The objective of this research paper is to conduct a cost benefit analysis (CBA) to identify cost effective mitigation techniques for efficient rail freight traffic management in Europe, by 2050. Reviewing previous derailments and studies, eight sets of derailment causes are analysed and, for each of them, sets of mitigation techniques are aimed at for their alleviation. The study finds that the highest cumulative costs of derailment are associated with 'wheel failure', while the lowest cumulative cost is identified for 'excessive track width'. Regarding mitigation techniques, the lowest cumulative benefits are demonstrated for 'track height' interventions, whereas 'wheel failure' alleviation demonstrates the highest benefits, in value terms (all by 2050). In most cases, the benefit to cost ratio did not exceed 2.6; in two cases ('track height' and 'rail failures') the ratio remained below 1 – a negative outcome where cost is higher than benefit. The study suggests that the most cost-efficient interventions are those applied to 'hot axle box and axle rupture' and 'spring and suspension failure'.

Keywords: traffic management; rail freight; train derailments; mitigation technique; impact; long-term; CBA; Europe

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1. Introduction

A railway derailment causes different types of loss and damage - to infrastructures, vehicles, rail and passenger service operations, and people - causing injury or death. The impact on railway traffic management and operational service quality is huge. Analysing mainline derailments on European railways, a study within the D-RAIL (2012b) project identifies three major causes, ordering the associated derailments into the following categories: *Infrastructure failures* (34%); *Rolling Stock failures* (38%); *operational failures* (22%); *weather, environment and 3rd Party causes* (2%); and unspecified (4%). While some derailments are classified as less severe, the consequences of serious rail freight derailments may result in variety of costs, including infrastructure; rolling stock; operational disruption; fatalities; litigation; third party damage; cost of attendance of emergency services; environmental costs; loss/damage/delay of cargo and loss of freight business.

The European Railway Safety Directive requires the National Safety Authorities (NSAs) of the Member States to report significant accidents (defined as accidents either causing fatalities or with total damages in excess of €150k) to the European Railway Agency (ERA) and to EUROSTAT (for statistical information), as defined in Regulation (EC) No 2003/91 (ERA, 2010, p. 13). Data for the period 2004-2009 show approximately 600 open line freight train derailments each year, more than 50% of them severe. Subsequently ERA (2012) adjusted this estimate to 500 open line freight derailments per year for 2011. Clearly then, prevention and mitigation of

derailments are vital for safe and cost effective operation of railway services (European Railway Agency, 2014).

1.1. Objective

The current research aims to conduct a monetisation of rail freight derailments and an evaluation of mitigation techniques, using Cost Benefit Analysis (CBA) which is a quantitative tool, widely used by academics and decision makers, to determine a project's appropriateness, efficiency and effectiveness (Litman, 2003; Mishan and Quah, 2007; Priemus, et al., 2008; Venables, 2007). Even a critical review of the tool (Mackie, 2010, p. 5) accepts that: 'there is a well codified history and development of practice'. It identifies costs and benefits, often converting them into monetary values, in order to show the long-term (e.g. 40 years for the current study) effects of the proposed solution(s). Thus, to contribute to the advances in rail traffic management and planning, the objective of this research paper is to conduct a CBA to find cost effective mitigation techniques for reducing, by 2050, the impact of freight train derailments in Europe.

1.2. Limitations of the analysis

Regarding the limitations of CBA, some experts (e.g. Mackie, 2010) opine that it is: 'a controversial tool, generating accusations of unacceptable principle, improper application, inadequate evidence base and bias'. Mackie and Preston (1998) identified as many as twenty-one errors and bias in the application of the CBA tool for appraisal of projects. In the area of transport these include incorrect transport inputs, errors in planning assumptions, prior political commitment, inaccurate data on the

current situation, and interactions with other transport options not being taken into account.

There are four main constraints or limitations in the current CBA. First, it limits itself to rail transport, excluding other potential impacts. For example, a prevention measure could, in the future, increase rail demand by shifting traffic from road, consequently causing decongestion, decreased transport costs, lower environmental impact etc. This study is based on the results of previous studies conducted under the D-RAIL project, such as 'Rail freight forecast to 2050' (for demand projection) (D-RAIL, 2012a); 'Future Rolling Stock Breakdown up to 2050' (for rolling stock quantity) (D-RAIL, 2013); 'Report on Derailment Economic Impact Assessment' (for definition of cost) (D-Rail, 2012b).

Secondly, the analysis focuses only on the rail freight perspective, excluding the cost analysis of rail passenger demand. This is due to the nature of the study, which investigates derailments in the freight sector only. More specifically, even though it is certain that the implemented interventions in the railway network will have a positive impact for passenger trains (European railways are used by both freight and passenger trains), this is not accounted for in the cost and benefit results. Thirdly, the study assumes that the technology and its costs will remain the same throughout the coming 40 years. Finally, the analysis limits itself to studying derailment costs only, excluding from the model other costs for rail freight transport. This is due to the assumption that the basic transport costs (€/tonne) will remain the same for each type of intervention/mitigation technique. However, it is already mentioned (in section 1.1) that CBA is a widely used tool for estimating economic benefits (compared to its costs) of a project and accordingly, this research has adopted this tool.

2. Methodology

The CBA applies two approaches: top-down and bottom-up. The top-down approach for cost savings intends to indicate the cumulative amount which could be spent on mitigation measures by 2050 and, consequently, to find which mitigation measures would be affordable, effective and efficient enough to achieve a derailment cost reduction of 10-20% in the EU by 2050. The bottom up approach of cost analysis employs the Benefit-Cost Ratio and the costs and benefits throughout the project duration. Based on these results, each intervention is assessed for its effectiveness. For this we need a comprehensive and balanced analysis approach, where the performance of an infrastructure or intervention/mitigation measure and its total cost accrued over the entire life-cycle are taken into account (Frangopol and Liu, 2007). Keeping this on board, this research first defines the costs per intervention; only long term mitigation measures are considered for the research, as previous study suggests that most short and medium term mitigation measures have a low effect on reducing the economic impact of derailments (European Railway Agency, 2012; D-RAIL 2012b). For each mitigation measure, the current research defines three types of costs: the implementation (investment and reinvestment); the maintenance costs that differ per intervention; and the avoided derailment costs. These costs are identified per cause of derailment and per frequency of occurrence.

The methodology for performing the economic analysis is based on European guidelines (by the European Commission, 2008) and the guidance on the use of cost benefit analysis for investment regarding health and safety on British railways (by the Office of Rail Regulation (ORR, 2008)). The CBA tool employs the flows of real

resource costs and benefits, but without taxes and subsidies. In its analysis, CBA attempts to monetise intangible costs and benefits that are directly connected to the use of the financial resources. For example, expenditure on interventions that reduce the occurrence of derailment directly decreases the environmental costs of derailment. Such costs (accidents, environmental, etc.) are therefore monetised and included in the CBA. The benefits included in the analysis come from financial (project revenues), environmental, safety and other perspectives. With the exception of revenues, the benefits are monetised as part of costs. All monetary values are converted into constant market prices. As the costs and benefits are calculated as time-series (lifetime of the project), a discounted rate is applied, in order to bring them together over time. Finally, the CBA results are based on several assumptions, such as the frequency of events, the efficiency factor of the intervention, other likely consequences, etc. It is therefore very important to perform a sensitivity analysis for the uncertainty parameters of the CBA model. The output of this analysis is the benefits to costs ratio expressed as:

$$\left(\frac{Benefit}{Cost}\right)_j = \sum_{i=1}^{40} \frac{Benefits}{Costs}$$

Where j = the intervention (mitigation technique)

And i = project duration 1--- 40 years

Besides the CBA results for the years 2020, 2030, 2040 and 2050, the study examines separately the costs and benefits for the sets of interventions. The D-RAIL Study (2012) identified the following intervention techniques:

- *Hot box detectors* - A wayside based intervention which measures the temperature of bearings, using infrared sensors.

- *Track Geometry Measurement System* - A vehicle based optical, no-contact and inertial track geometry measurement system, which is able to provide automatically the main geometric parameters of the track.
- *Dynamic axle load checkpoint* - A wayside track-based monitoring system which measures the dynamic wheel rail forces over a distance of six sleeper spans.
- *Wheel Profile and Diameter system* - A vehicle based, no-contact real-time wheel measurement system, which is able to perform in-service automatic optical measurement of the wheel sets. The system acquires all major wheel parameters. Systems analysis and reporting software provides wheel performance trending and predictive identification of faulty components. The system can be installed either at a depot entrance or in line.
- *Laser based wear measurement: Rail profile measuring system* - A vehicle-based, optical, no-contact Laser triangulation. The system provides accurate and immediate reporting on the profile and wear condition of the rail whilst travelling at track speeds. It can be used for grinding checking or for maintenance application. By means of the analysis software, it compares the worn profile to the original, allowing the maintenance team to detect areas with a problem.
- *Video Inspection of rail techniques*: includes Track Head Inspection System, Track Inspection System and Track Surface Inspection System - which are all vehicle-based systems.

Preventative techniques have been thoroughly examined in other studies (e.g. European Railway Agency, 2009 and European Railway Agency, 2012). To avoid duplication, this study focuses on examining mitigation techniques. Based on the

causes of derailments, the above interventions were reclassified as bundles towards one cause of derailment. Studying derailments in different European countries, such as Germany, UK, Austria, the D-RAIL Study (D-RAIL, 2012b) identified the following eight main causes for derailments in Europe:

- Hot axle box and axle journal rupture (Rolling stock)
- Excessive track width (Infrastructure)
- Wheel failure (Rolling stock)
- Skew loading (Operations)
- Excessive track twist (Infrastructure)
- Track height/ cant failure (Infrastructure)
- Rail failures (Infrastructure) and
- Spring and suspension failures (Rolling stock)

The study linked the eight causes of derailment to three main types: Operational, Infrastructure and Rolling stock (discussed in section 1), representing 55% of the total number of accidents and the higher rated types of costs. For its cost benefit analysis, the ERA (European Railway Agency 2009) study used 500 derailments per year, as did the DNV study (DNV, 2011a, p.23). In line with these European rail derailment studies, the current study uses 500 derailments per year and assumes two scenarios for the analysis: (1) the constant derailments scenario, where the number of annual derailments remains equal to 500 throughout the analysis period up to 2050 and (2) the decreasing derailments scenario which is broken down into:

- (2a) Decreasing derailments by 15% (by 2050)

- (2b) Decreasing derailments by 10% (by 2050)
- (2c) Decreasing derailments by 20% (by 2050)

2.1. Calculation of costs

The types of avoided derailment costs are: environmental, infrastructure, operation, rolling stock, human factor and unspecified. The study acknowledges that there are additional types of related derailment costs - such as image costs resulting from derailments, delivery delay costs, passenger transport delay costs - whose values were very difficult to identify, hence these were not included in the calculations. In addition, there are ancillary benefits from applying derailment mitigating wayside measures, for example, less maintenance of rail tracks and equipment, decreased fuel costs (for details see Resor et al., 2004 and Zarembski et al., 2003), increased lifespan of rail tracks); however, due to lack of data for the current estimation, these were also not included in the analysis.

Place Fig. 1 about here

Figure 1 depicts the rationale for the bottom-up analysis. The basic idea is to attribute the costs to the benefits, i.e. if we apply a specific set of interventions, what the effect will be. The study incorporates nine types of intervention measures and eight causes of derailment. For each individual cause of derailment a set of interventions is allocated. In addition, its potential impact is identified, based on the share of derailments resulting from this cause. This relation is depicted in Table 1. In principle, the second column presents the cost of each SET of derailment cause. This means that if there are 500 accidents due to 'Hot axle box and axle journal rupture (SET 1 in column 1); this would mean a total cost of €1,282,575 x 500. In

this example, (in SET 1) the combination of ‘Hot box and hot wheel detector systems’ (set of intervention/mitigation technique in column 3) can be applied to decrease the number of accidents caused by Hot axle box and axle journal rupture (derailment cause – SET 1), impacting (benefiting) a maximum of 12% (in column 4) of the total number of 60 derailments (in column 5).

Place Table 1. About here

For each one of the interventions the study sets the investment (implementation), reinvestment and maintenance costs in 2012 market prices. The investment and reinvestment costs are expressed as the combination of capital repayments (as a simplification, it is equal to the depreciation of the intervention over its lifetime) and the financing costs, which are defined as the original investment minus the cumulative depreciation. The reinvestment costs are applied depending on the lifetime of the intervention; in most cases these are applied every 10 years and occasionally every 15 years. The maintenance costs are the same per year.

The equations for deriving the total costs for each intervention are presented below:

$$\text{Capital Repayment}_i = \frac{\text{Total Installation or reinvestment costs}}{\text{Project life time}_i}$$

$$\text{Net Book Value}_i = \text{Net Book Value}_{i-1} - \text{Capital Repayment}_{i-1}$$

$$\text{Financing Cost}_i = \text{Real Cost of Finance} \times \text{Net Book Value}_i$$

Where, Real cost of Finance = 0.006 (as per the guide of ORR, 2008)

And i = project duration 1--- 40 years

$$\text{Total Cost}_i = \sum_{i=1}^{40} (\text{Capital Repayment} + \text{Financing Cost} + \text{Maintenance Cost})_i$$

2.2. Calculation of benefits

The second type of costs is actual derailment costs; these are used for the calculation of benefits and comprise – in common with both the DNV (2011a and 2011b) and ERA (2009) studies - the environmental risks costs, the human risks costs, the system costs (i.e. infrastructural operational and rolling stock), and the unspecified risks costs (depending on the cause of derailment; for example the derailment costs for Hot axle box and journal rupture). The average cost per derailment for all reported derailment instances was calculated as €802.360 by the previous study (D-Rail, 2012b p.13), which is also applied in this analysis. Table 1 presents the costs (column 2) specifically for the causes (column 1) studied in this report. The derailment costs are expressed as total costs for a certain number of derailments per year. These are defined individually per cause of accident in terms of impact (percentage and number of avoided derailments; columns 4 and 5 respectively in Table 1) and costs (specific costs of derailment depending on the cause in column 2 of Table 1). For example, Hot box & hot wheel detector systems can decrease the total number of accidents by maximum 12%, i.e. 60 accidents; this number is the number attributed to the cause of Hot axle box and axle journal rupture. The benefit per accident (see Table 1, second column) is calculated at €1,282,575 - the cost estimated for derailment caused by axle ruptures. Hence, by applying Hot box & hot wheel detector systems, the total annual cost savings can be up to $(1,282,575 \times 60 =)$ €76,954,500.

3. CBA Results

3.1. Cost scenarios

The cost scenarios are developed estimating the cost reductions that can be achieved based on the assumption of two scenarios (and sub-scenarios) noted in Figure 2. The number of accidents is expected to decrease from 500 to 425 (using the 15% assumption for 2050 results), concluding a negative growth rate of 0.41% annually. In the case of 10% decrease, the number falls to 450 and a negative rate of 0.26% pa. Finally, in the case of 20% decrease, the number falls to 400 with a negative rate of 0.56% annually. Regarding the intermediate targets for 2030, scenario 2a shows derailments decreased by 8% (compared to the 500 derailments in 2010);, with scenario 2b showing a decrease of 5% and 2c, of 11%.

3.2. Top down results

Using the assumption that the average derailment cost is €802,360, the total costs over the 40-year horizon were calculated as the sums of a geometric progression. The formula used was:

$$\sum Total\ Costs = Average\ Derailment\ Cost \times \frac{(1 - \lambda)v}{(10 - \lambda)}$$

Where λ equals is the derailment growth rate and v equals to the number of years. The total derailment costs per year, for the baseline year 2010, are estimated at €401,181 thousand.

Assuming a constant rate of derailments, the costs over 40 years are more than €16 billion – an average of €401 million annually (see Table 2). This cost over 40

years is expected to decrease (i.e. cost savings) by (€16 billion – €14.84 billion = €1.16 billion); in the case of a 15% decrease in derailment, about €1.2 billion € is achieved. Using the spectrum of 10-20%, the cost savings can range from €0.8 billion to €1.6 billion. Table 3 displays cost savings for the intermediate years of 2020, 2030 and 2040.

Place Fig. 2 about here

Place Table 2 about here

Place Table 3 about here

3.3. Bottom up result through cost benefit analysis

The costs and benefits as well as the BC ratio are calculated for each set of mitigation techniques. The costs here refer to the investment, reinvestment and maintenance costs (see Table 4). All costs are defined in 2012 values. For the wayside interventions (hot box detectors, dynamic axle load checkpoints and wheel profile and diameter monitoring systems), the number of units was estimated based on the network length. On the other hand, the vehicle-based number of units was estimated using two units per country. It should be noted here that the setting of definition of costs was challenging, due to data limitations, and different cost definitions and assumptions were made as and when necessary, based on expert opinion. The analysis excluded operational costs, as it was not possible to define these for the examined interventions. The same was done for disposal/ inspection/ training costs.

Place Table 4 about here

While the annual benefits for each set are constant every year, the annual costs differ depending on the reinvestment costs and the lifetime of the project, assuming that maintenance costs are the same each year. Our analysis finds (due to data restrictions, the details of the analysis are not provided) that SETS 3, 4 and 7 depict the highest cumulative costs - all above €0.5 million by 2050. SET 3 is particularly high in terms of costs (€1.8 million by 2050), applying two types of measures including wheel profile monitoring, which depicts the highest costs per unit for wayside applications. SET 7 also demonstrates very high costs, as it implements several types of video inspection measures, which also have high costs per unit. SET 4 has cumulative costs of almost €0.6 million. SETS 1 and 3, followed by SET 8 depict the highest cumulative benefits (€2.7, €3.5 and €1.9 million by 2050 respectively) due to:

- The high number of avoided derailments per year (impact fact based on the cause of derailments) and
- The high costs allocated with these derailments (severity of the cause).

Based on the results above, the Benefit Cost (BC) ratios were produced (see Table 5 and also presented in graphical form in Annex 1). Only scores over 1 can be considered positive results (i.e. benefit is higher than cost) and only SETS 1 and 8 achieve a BC ratio of more than 3. At the same time, the sensitivity analysis (discussed in the next section) also provides positive results for these two sets of mitigations, as the benefits from avoided derailments are very high (see also column 5 of Table 1). From Table 5 we find that SETS 2 to 5 demonstrate positive but moderate results, with BC ratios between 1 and 3, while SETS 6 and 7 depict values

less than 1, i.e. for these sets costs are always higher than the benefits. In the presence of a constrained budget, a rationed resource is needed and for this, Mackie (2010, p. 18) argues for a minimum cut-off BC ratio being required. Although the investors will be the ultimate decision makers, the study recommends BC ratio 3 as a cut-off point.

Place Table 5 about here

3.4. Sensitivity analysis

The results of the BC analysis were revised (see Tables 6-9) for the following assumptions:

- Decrease avoided derailments (i.e. effectiveness) by 10% (see Table 6).
- Reduce costs by 10% (see Table 7)
- Increase costs by 10% (see Table 8)
- Decrease avoided derailments (i.e. effectiveness) by 10% AND increase cost by 10% (see Table 9)

Place Table 6 about here

Place Table 7 about here

Place Table 8 about here

Place Table 9 about here

Through the sensitivity analysis we find that the effects of adjusting avoided derailments and adjusting the implementation costs are quite similar: by decreasing each one of these factors by 10%, the BC ratios also similarly decrease; the same

relationship also occurred when increasing the costs by 10%. The impact on the BC ratio is a relative decrease of 18%, showing the linear combination of the BC ratio and the two factors in the model: i.e. if we double the limiting factors: -10% effectiveness and +10% costs, then the effect on the BC ratio is doubled (linear combination). (N.B. this is not exactly double due to the functions used, e.g. in technological depreciation, lifetime of intervention etc.) In summary, the results of the sensitivity analysis depict a high correlation of the variables.

3.5. Comparison of the findings of top down and bottom up analysis

According to the top-down approach, €1.2 billion can be spent until 2050 (year 40) for the decrease in derailments of 15% (see section 3.2). Based on our assumptions, none of the defined sets of measures can itself reach a decrease of 15% (of 500) i.e. 75 avoided derailments annually. SET 1 (Hot box & hot wheel detector systems and Acoustic bearings detectors) and SET 3 (Axle load checkpoints, Wheel profile and diameter systems, Wheel surface inspection systems and Hot wheel detector systems) have an expected impact of 12% and 10.3% (see Table 1) avoided derailments, respectively. However, when comparing the average derailment cost (€802,360) to the individual cost savings, the impact increases significantly for these two sets, as well as for SET 8 (Axle load checkpoints and on board accelerometer systems). For example, the cost of SET 1 avoided derailment is €1.3 million (actually €1.28 to be precise)- much higher than the average derailment cost (i.e. $60 \times €802,360$).

In terms of costs and benefits, the techniques of both SET 1 and SET 8 are, in cumulative terms, cost efficient; based on our assumptions, the individual cumulative

costs are not more than €0.4 billion and the benefits can reach up to €3 million and €2 million, respectively.

Here, it should be noted that these numbers differ for the intermediate years (see Table 3) of the top-down approach. For example, while in total the actual cumulative expenditures are lower than the attributed amount of the top-down approach, for SET 1 the cumulative costs are €0.47 billion - much lower than the average of €1.2 billion (discussed in section 3.2). For year 10, the cumulative costs for SET 1 are €137 million – less than €60 million of the top down approach. For SET 8 the results are similar, as the cumulative costs for year 10 are €114 million. In fact, there is no set of interventions examined which depicts cumulative costs of less than €72 million, by year 10.

However, the benefits coming from SETS 1 and 8 are much higher than the ones expected in the top-down analysis, due to the high values of avoided derailments. In addition, by year 20, the situation changes; for the examples of SETS 1 and 8, these numbers (also see Figure 3) are €243 million and €208 million, i.e. less than the €301 million allocated, on average, for that purpose.

In terms of totals, only SET 3, with €1.8 billion, is not within the cost range covered in Table 3.

4. Summary

Rail freight derailment causes different types of costs, to infrastructure, vehicles and traffic management, for both passenger and freight services. It also causes injuries, fatalities and damage to the environment. Even if derailment cannot be eliminated completely, for an effective, efficient and safe rail freight operation, it is

imperative that the occurrence of derailments be reduced, through intervention techniques that can be preventative and/or mitigative. Since previous studies have thoroughly examined and analysed the costs and benefits of preventative techniques, this study focuses on examining mitigating techniques, using the cost benefit analysis (CBA) tool. This paper reports on the potential costs and benefits of interventions for rail freight derailment in Europe, up to 2050. The study is based on current (2012) data (on costs and technical details) and any changes in the technology or economy in the coming years are excluded from the assumptions of the analysis. In line with previous European rail derailment studies, the current study uses 500 derailments per year and assumes two scenarios for the analysis: (1) the constant derailments scenario and (2) the decreasing (10% to 20%) derailment scenario.

The number of annual derailments remains equal to 500 throughout the analysis period (up to 2050) in the first scenario and, for the same period, the decreasing derailments scenario is broken down into three sub-scenarios:

- (2a) Decreasing derailments by 15% (by 2050)
- (2b) Decreasing derailments by 10% (by 2050)
- (2c) Decreasing derailments by 20% (by 2050)

The findings of the previous studies of cost benefits analyses of freight derailments, that focus on preventative measures, highlighted that investment in interventions for the whole of the European rail network are not justified, feasible or economically viable, as their impact is limited. The results of those studies were also demonstrated via cost-benefit ratios, which were within the range of zero to three, applying several assumptions. The current analysis uses a different analytical approach; first, it applies a top-down approach, estimating the cost savings based on

an average, e.g. 15%, decrease of derailments; then it elaborates, using a bottom-up approach (to identify cost efficient mitigation intervention), on a set of interventions up to 2050. The results of the top-down approach estimate that, based on a decrease in derailments of 10% to 20%, the decrease in costs accumulates to €0.8 billion and €1.6 billion respectively, by 2050. This amount is then compared to the bottom-up results, to identify cost-efficient mitigating solutions.

The research explored nine derailment intervention techniques: Hot box detectors (wayside-based); Track Geometry Measurement System (vehicle-based); Dynamic axle load checkpoint (wayside-based); Wheel Profile and Diameter system (vehicle-based); Laser based wear measurement (vehicle-based); and Video Inspection of rail techniques (broken down to three vehicle-based techniques). Their combinations establish eight sets of interventions, targeting their common causes. These were explored using a cost-benefit model focusing on:

- investment/ reinvestment and maintenance costs (cost-side) and
- cost savings from derailment mitigation (benefit-side)

The highest costs are demonstrated for SET 3 (wheel failure cause), with an impact of 10% in decreasing derailments, adding up to €1.8 billion; however, SET 3 also demonstrates the highest benefits, with almost €4 billion by 2050. The lowest cumulative costs - less than €400 million each - are identified for SET 2 (excessive track width), SET4 (skew loading) and SET 8 (spring and suspension failure). The lowest cumulative benefits are demonstrated for SET 6 (track height).

Place Fig. 3 about here

The benefit to cost ratios in most cases did not surpass 2.6; in fact for two cases (SET 6 - track height and SET 7 – rail failures), the ratio remained below 1 (i.e. cost is higher than benefit, meaning a negative outcome). For SET 1 (hot axle box and axle rupture) and SET 8 (spring and suspension failure), the results were positive, reaching a benefit cost ratio of greater than 5, by 2050. In addition, both of them were cost-efficient, with less than €0.5 billion of accumulated costs. However, for SET 8 (spring and suspension failure), the impact on the number of derailments is no more than 6%. For SET 1, this percentage reaches 12%. For the remaining sets of mitigation techniques, the BC ratios remained less than 3.

5. Conclusions

The study concludes that the mitigation techniques ‘Hot box & hot wheel detector systems’ for SET 1 (hot axle box and axle rupture derailment) and ‘Axle load checkpoints’ for SET 8 (spring and suspension failure derailment) are the most cost effective. Readers are requested to consider the findings of the analysis with caution, due to the fact that they do not consider the costs and benefits of a mitigation measure for a specific rail network, location or situation. The research has used an average value of benefits and thus provides overall understanding and insights. Further in-depth analysis will be required for specific locations and conditions.

The general assumptions (discussed before, in particular in Sections 1.2 and 2) of the current study offer opportunities for areas of future research work. For example, the assumption of a bundle of interventions is that they target the same derailment cause (see section 2). In reality their effect is considered independently. The dependency of different mitigation measures and their combined effects are also potential future areas of research. Moreover, the effects for simple network

maintenance, or the benefits for passenger trains, are not part of the analysis in this study and can be explored in future research. Also, this paper presents only technical solutions, whereas further research could investigate policy options for prevention and mitigation of derailments. There is potential dependence of one mitigation technique on another e.g. fixing wheels may reduce the impact on rail track and potentially reduce rail failure. Future research work can also examine the independence of assumptions.

The impact of the study is that the current economic assessment is expected to provide an improved understanding to railway infrastructure managers, freight train operators and National Safety Authorities, as well as enriching the literature in the field on the magnitude cost of rail freight derailments and the potential benefit of applying mitigation techniques. This is an important step before any derailment detection and mitigation measures are proposed, to ensure that they are affordable and adoptable by relevant stakeholders.

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References

- DNV, 2011a. Assessment of freight train derailment risk reduction measures Part B Final Report. Report for European Railway Agency. Report No: BA000777/09, 20 October.
- DNV, 2011b. Assessment of freight train derailment risk reduction measures A1 – Existing measures. Report for European Railway Agency. Report No: BA000777/02, 18 April.
- D-RAIL, 2013. Future Rolling Stock breakdown to 2050. D-RAIL - Development of the Future Rail Freight System to Reduce the Occurrences and Impact of Derailment. Deliverable D2.1, Final version, 25 March.
- D-RAIL, 2012a. Rail Freight Forecast to 2050. D-RAIL - Development of the Future Rail Freight System to Reduce the Occurrences and Impact of Derailment. Deliverable D2.1 Final version, 31 July.
- D-RAIL, 2012b. Report on Derailment Economic Impact Assessment. D-RAIL - Development of the Future Rail Freight System to Reduce the Occurrences and Impact of Derailment. Deliverable D1.2, Final version, 30 November.
- Elvik, R., 2009. An exploratory analysis of models for estimating the combined effects of road safety measures. Accident Analysis & Prevention. 41 (4), July, 876–880.

European Railway Agency, 2014). Annual Report 2013. European Union. Retrieved from www.era.europa.eu

European Railway Agency, 2012. Prevention and Mitigation of freight train derailments at short and medium terms. ERA/REP/02-2012/SAF, February.

European Railway Agency, 2009. Impact Assessment on the use of Derailment Detection Devices in the EU Railway System. RA/REP/03-2009/SAF, 7 May.

European Commission, 2011. White Paper Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system. COM(2011) 144 final. Brussels, March.

European Commission, 2008. Guide to Cost Benefit Analysis of Investment Projects. DG of Regional Policy.

Eurostat, 2012. Railways Length of Lines in Use. EU Transport in Figures Statistical Pocketbook 2012. Paragraph 2.5.3.

Evans, A.W. 2011. Fatal train accidents on Europe's railways: 1980–2009. Accident Analysis and Prevention. 43, 391–401.

Evans, A. W., 2012. The Economics of Railway Safety. Manuscript of a paper to be published in a special issue of Research in Transportation Economics on transport safety. Imperial College London, April.

Frangopol, D.M., Saydama, D., Kim, S., 2012. Maintenance, management, life-cycle design and performance of structures and infrastructures: a brief review. Structure and Infrastructure Engineering: Maintenance, Management, Life-Cycle Design and Performance. 8 (1),1-25.

- Frangopol, D. M., 2011. Life-cycle performance, management, and optimisation of structural systems under uncertainty: accomplishments and challenges. *Structure and Infrastructure Engineering: Maintenance, Management, Life-Cycle Design and Performance*. 7 (6), 389-413.
- Frangopol, D. M., Liu, M., 2007. Maintenance and management of civil infrastructure based on condition, safety, optimization, and life-cycle cost. *Structure and Infrastructure Engineering: Maintenance, Management, Life-Cycle Design and Performance*. 3 (1), 29-41
- Litman, T.A., 2003. Transportation cost analysis: techniques, estimates and implications. Victoria Transport Policy Institute, June, Transportation Research Board: trid.trb.org
- Mackie, P. J., 2010. Cost-benefit analysis in transport: a UK perspective. Discussion Paper 16), Mexico, 26- 27.
- Mackie, P.J., Preston, J.M., 1998. Twenty-one sources of error and bias in transport project appraisal. *Transport Policy*. Vol 5 (1).
- Mishan, E.J., Quah, E., 2007. *Cost Benefit Analysis*. Fifth Edition, Routledge, Abingdon, UK and New York, USA
- Office of Rail Regulation UK (2008). Internal guidance on cost benefit analysis (CBA) in support of safety-related investment decisions. <http://www.rail-reg.gov.uk/server/show/nav.1118>
- Priemus, H., Flyvbjerg, B., van-Wee, B., (ed) 2008. *Decision-making on Mega-projects: Cost-benefit Analysis. Planning and Innovation*. Edward Elgar Publishing Ltd (Cheltenham, UK and Massachusetts, USA).

Resor, R., Zarembski, A., Patel, P., 2004. Factors Determining the Economics of Wayside Defect Detectors. Proceedings of the 83rd Annual Meeting of the Transportation Research Board. Washington, DC.

Venables, A, J., 2007. Evaluating Urban Transport Improvements: Cost-Benefit Analysis in the Presence of Agglomeration and Income Taxation. Journal of Transport Economics and Policy. Vol. 41(2), May, 173-188.

World Bank, 2005. Notes on the Economic Evaluation of Transport Projects TRN – 6, January.

Zarembski, A., Resor, R., Patel, P., 2003. Economics of Wayside Inspection Systems. American Society of Mechanical Engineers.

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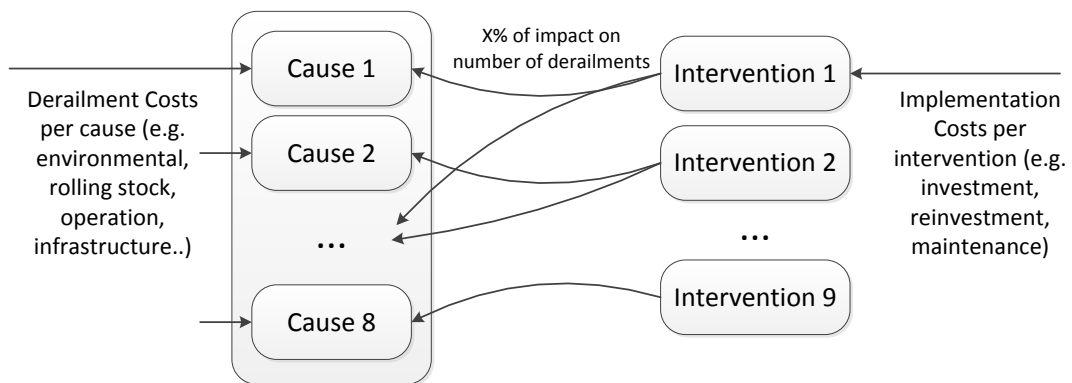


Fig. 1. Bottom up approach of calculating costs and benefits.

Table 1. Cost per derailment cause and impact (benefits) per intervention set.

Derailment causes	Individual SET's costs in € (2012 values)	Set of intervention/mitigation	Impact	Annual number of avoided derailments
SET 1. Hot axle box and axle journal rupture	1,282,575 €	Hot box & hot wheel detector systems	12%	60
SET 2. Excessive track width	474,966 €	Track geometry measurement systems	8.60%	43
SET 3. Wheel failure	1,879,471 €	Axle load checkpoints	10.30%	52
SET 4. Skew loading	833,144 €	Axle load checkpoints	5.95%	30
SET 5. Excessive track twist	552,627 €	Track Geometry measuring systems	6.58%	33
SET 6. Track height/cant failure	281,922 €	Track Geometry measuring systems	3.40%	17
SET 7. Rail failures	587,025 €	Track internal inspection systems (NDT: Ultrasound, Eddy Current, Magnetic flux)	2.87%	14
SET 8. Spring & suspension failure	1,865,570 €	Axle load checkpoints	5.62%	28
Average derailment cost for the specified causes	1,094,639€	Total impact from interventions	55%	277

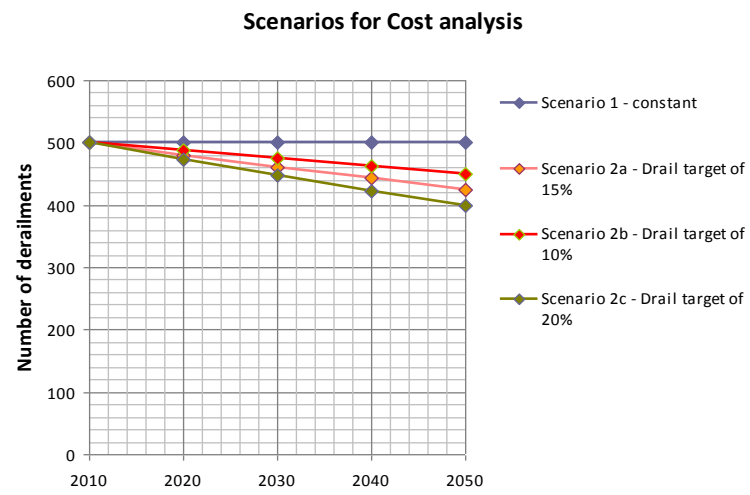


Fig. 2. Cost scenarios for two scenarios.

Table 2. Top-down results in thousand €.

Costs (thousand €)	2010 annual costs	2030 annual costs	2050 annual costs	Cumulative Costs (2010- 30)	Cumulative Costs (2010-50)
Scenario 1 - constant derailment number	401,181	401,181	401,181	8,023,610	16,047,220
Scenario2a - 15% derailment decrease	401,181	369,870	341,003	7,721,932	14,841,202
Scenario 2b - 10% derailment decrease	401,181	380,593	361,062	7,826,228	15,250,840
Scenario2c - 20% derailment decrease	401,181	358,827	320,944	7,613,395	14,423,022

Table 3. Cumulative cost savings in €.

Costs savings (thousand €)	By 2020	By 2030	By 2040
Scenario 1 - constant derailment number	-	-	-
Scenario 2a - 15% derailment decrease	72,415	301,678	681,544
Scenario 2b - 10% derailment decrease	47,158	197,382	447,993
Scenario2c - 20% derailment decrease	98,955	410,215	922,261

Table 4. Definition of costs per intervention.

Derailment interventions	Lifetime (years)	Investment cost (€) per unit	Reinvestment cost (€)per unit	Annual maintenance costs per unit
Wayside based - Hot box detectors	15	229600	147600	7380
Vehicle based - Track Geometry Measurement System (e)	10	950000	570000	76000
Wayside based - Dynamic axle load checkpoint	10	110000	73000	13000
Wayside based - Wheel Profile and Diameter monitoring system (e)	10	475000	285000	38000
Vehicle based - Laser based wear measurement: Rail profile measuring system (e)	10	300000	180000	24000
Vehicle based - Video Inspection of rails: Track Head Inspection System (e)	10	400000	240000	32000
Vehicle based - Video Inspection of rails: Track Inspection System (e)	10	800000	480000	64000
Vehicle - based Video Inspection of rails: Track Surface Inspection System (e)	10	450000	270000	36000

Table 5. BC ratio for effectiveness = 1.

Derailment cause	Y10	Y20	Y30	Y40
SET1. Hot axle box and axle journal rupture	5,61	6,32	6,96	7,19
SET2. Excessive track width	2,13	2,45	2,58	2,64
SET3. Wheel failure	1,83	2,06	2,30	2,30
SET4. Skew loading	1,56	1,73	1,90	1,90
SET5. Excessive track twist	1,71	1,78	1,99	1,95
SET6. Track height/cant failure	0,45	0,51	0,58	0,58
SET7. Rail failures	0,39	0,44	0,50	0,50
SET8. Spring & suspension failure	4,60	5,02	5,49	5,48

Table 6. BC ratio for effectiveness = 0.9 with 10% decrease in avoided derailments (Sensitivity results).

Derailment cause	Y10	Y20	Y30	Y40
SET1. Hot axle box and axle journal rupture	5.05	5.69	6.27	6.47
SET2. Excessive track width	1.92	2.20	2.32	2.37
SET3. Wheel failure	1.65	1.85	2.07	2.07
SET4. Skew loading	1.41	1.55	1.71	1.71
SET5. Excessive track twist	1.54	1.61	1.79	1.75
SET6. Track height/cant failure	0.41	0.46	0.52	0.52
SET7. Rail failures	0.35	0.40	0.45	0.45
SET8. Spring & suspension failure	4.14	4.52	4.94	4.93

Table 7. BC ratios for decreasing costs by 10% (Sensitivity results).

Derailment cause	Y10	Y20	Y30	Y40
SET1. Hot axle box and axle journal rupture	6.24	7.02	7.74	7.98
SET2. Excessive track width	2.37	2.72	2.87	2.93
SET3. Wheel failure	2.03	2.29	2.56	2.56
SET4. Skew loading	1.74	1.92	2.11	2.11
SET5. Excessive track twist	1.90	1.98	2.21	2.16
SET6. Track height/cant failure	0.50	0.57	0.64	0.64
SET7. Rail failures	0.43	0.49	0.55	0.55
SET8. Spring & suspension failure	5.11	5.58	6.10	6.09

Table 8. BC ratios for increasing costs by 10% (Sensitivity results).

Derailment cause	Y10	Y20	Y30	Y40
SET1. Hot axle box and axle journal rupture	5.10	5.74	6.33	6.53
SET2. Excessive track width	1.94	2.23	2.34	2.40
SET3. Wheel failure	1.66	1.87	2.09	2.09
SET4. Skew loading	1.42	1.57	1.73	1.73
SET5. Excessive track twist	1.55	1.62	1.81	1.77
SET6. Track height/cant failure	0.41	0.47	0.53	0.53
SET7. Rail failures	0.35	0.40	0.45	0.45
SET8. Spring & suspension failure	4.18	4.56	4.99	4.98

Table 9. BC ratio for effectiveness = 0.9 with 10% decrease in avoided derailments AND a 10% increase in costs. (Sensitivity results).

Derailment cause	Y10	Y20	Y30	Y40
SET1. Hot axle box and axle journal rupture	4.59	5.17	5.70	5.88
SET2. Excessive track width	1.74	2.00	2.11	2.16
SET3. Wheel failure	1.50	1.68	1.88	1.89
SET4. Skew loading	1.28	1.41	1.56	1.55
SET5. Excessive track twist	1.40	1.46	1.63	1.59
SET6. Track height/cant failure	0.37	0.42	0.47	0.47
SET7. Rail failures	0.32	0.36	0.41	0.41
SET8. Spring & suspension failure	3.76	4.11	4.49	4.48

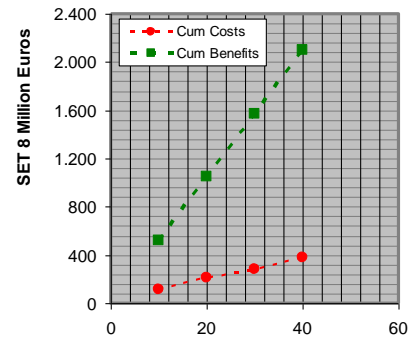
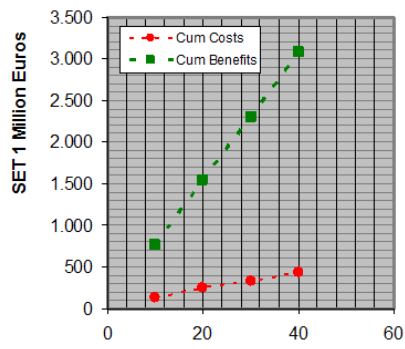


Fig. 3. Cumulative Costs and Benefits for SET 1 and SET 8 intervention techniques.

